DEVELOPMENT OF A SUBMERGED HUB FOR MONITORING THE DEEP SEA

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Abstract: *Understanding the ever-changing oceans, biota and atmosphere is one of the great global challenges of the next several decades. The future of measuring and forecasting long-term trends and variability in coastal ecosystems, weather, acoustics, and climate lies in sustained measurements of key ocean indicators from ocean observing systems. A new era in ocean observing has begun, one of an integrated, organized approach to gathering and sharing information. The University of Haifa and the University of Padova have joined forces and developed a submerged hub on top of the Texas A&M – University of Haifa Eastern Mediterranean Observatory (THEMO). THEMO is located in the Levant Basin of the Mediterranean Sea at a depth of 125 m. The developed hub includes processing units, energy cells, and interfaces to various sensors, and is designed to connect any underwater sensor to a cloud service in real time. In its first stage, the hub serves as a remotely accessed underwater acoustic modem for the aim of long-range underwater acoustic communication and to actively detect marine mammals and large predators. The hub conserves power and is suitable for long-term deployments (several months). By combining the RF communication capability of THEMO with a wired transmission from deep water to surface, the hub transfers the collected data to a shore station. This communication link is two-way and allows updating of the processing software onboard the hub from the shore. The communication between the hub and the shore station is managed to avoid bottlenecks. Moreover, the processing burden is divided between the submerged hub and a processor onboard the surface buoy. In this paper, we share some design details of our submerged hub, and discuss its capabilities. We then demonstrate the usage of our submerged hub, and invite the research community to use its data.*

Keywords: *Marine Observatory, Underwater Acoustics, Marine Communication*

1. INTRODUCTION

Ocean observatories have been recognized as a key step towards a fuller understanding of the oceans. Applications include gathering of scientific data, pollution control, climate monitoring, and long-term observation of the marine biota. Recently, the discovery of natural gas off the coast of Israel has boosted the need for a high-end research facility to extend our knowledge of the Mediterranean Sea and for the development of marine technology.

Collaboration between Texas A&M University and the University of Haifa has

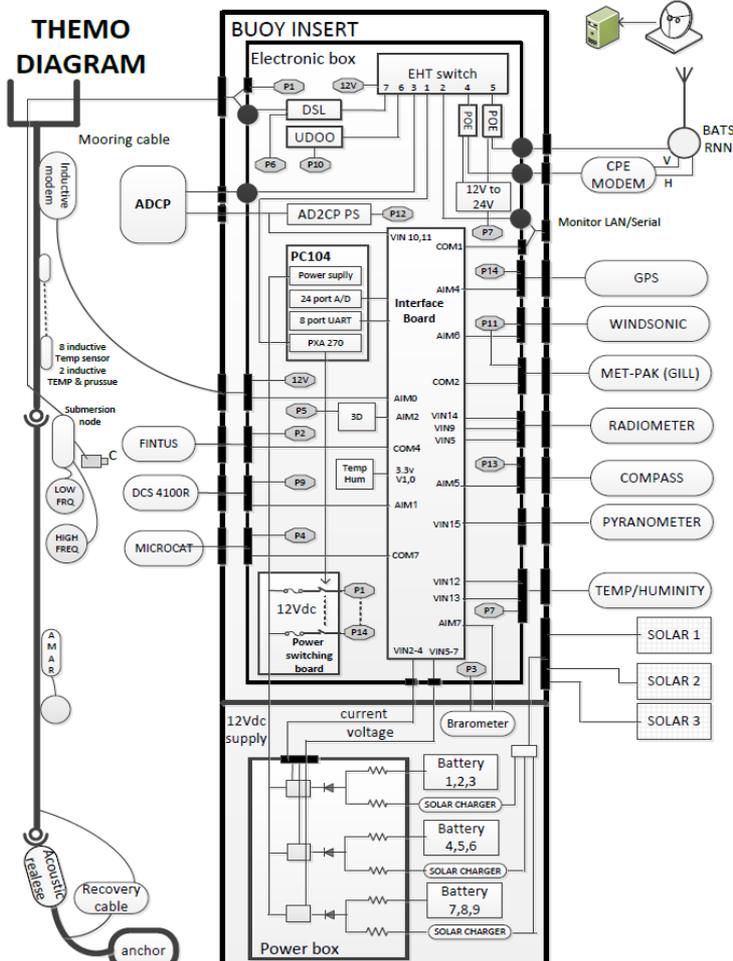Fig. 1: Locations of the two THEMO moorings

established a major Mediterranean observatory named "THEMO". The observatory is stationed off the coast of Northern Israel in two locations: a "shallow" mooring at water depth of 125 m, and a "deep" mooring at water depth of 1500 m. Fig. 1 shows the locations of the two moorings.

Each mooring includes a sensor array attached to a surface buoy supporting various sensor types: inductive temperature and pressure sensors, Fluorometers, Doppler current sensors, ADCP current meters, CTDs, meteorological sensors, and underwater acoustic sensors. The data from the submerged sensors is transmitted to a processor unit on board the surface buoy via both inductive communication and Ethernet. The location of the University of Haifa on top of Mt. Carmel some 600 m above sea level allows the transmission of the data from the surface buoy to a surface station via real-time RF communication. This makes THEMO a unique observatory with two-way communication capabilities. The data is received at a shore station and is

Fig. 2: Structure of the THEMO mooring

openly shared for view and download on a cloud service. The structure of the THEMO mooring is presented in Fig. 2.

In this paper, we present the technical details of a submerged hub mounted on the THEMO mooring at a depth of 90 m. The objectives of the hub is to provide the collection of acoustic data, its processing, and its transmission to shore. In addition, the hub was built to allow future sensor deployments such as underwater cameras. The immediate applications of the submerged hub are passive acoustic detection of marine mammals, active acoustic detection of large pelagic fish, measurement of acoustic ambient noise, and long-range underwater acoustic communications.

The submerged hub includes an energy source able to last for three months without charging, two processing units, two software defined acoustic modems, and an inertial system. The hub communicates with two processors on the surface buoy, and is remotely accessible from a shore station. The rest of this paper includes a discussion about the choice of the electrical components of the node (Section 2), and a description of the developed protocols (Section 3).

2. STRUCTURE OF THE THEMO SUBMERGED HUB
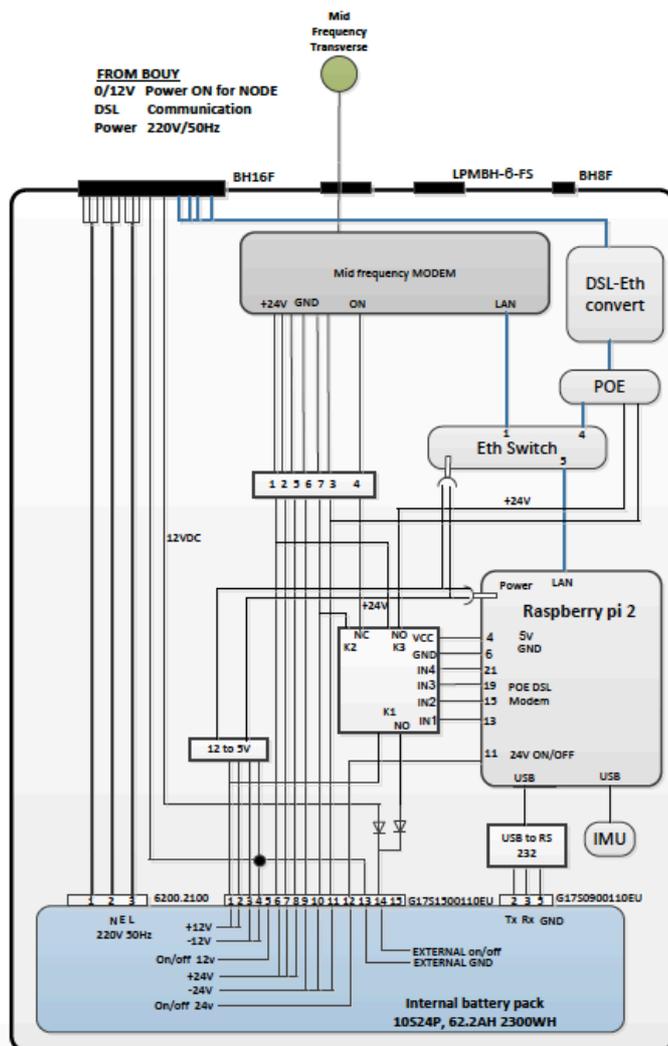
2.1. Components of the Submerged Hub

Fig. 3: Structure of the submerged hub

The goal of the THEMO submerged hub is to provide the infrastructure for multiple research applications that span beyond the ones identified now and supported by the mooring's standard sensors. As such, we have constructed the hub in a general manner, allowing the future addition of sensors and components. The current components of the hub include an inertial measurement unit (IMU), passive acoustic measurement system, a software defined underwater acoustic modem (SDM), and two processing units. The placement of these components is described in Fig. 3. The electrical components of the submerged hub support the following activities:

1. **Underwater Motion.** The hub will measure its underwater motion that is induced by internal waves and near bottom currents. Such measurements are used to calibrate numerical models of water currents, as well as to understand the long-term dynamics of the sea. On the Marine Technology side, these measurements will be used for the development

of high accuracy wave height estimation methods, as well as underwater dead-reckoning navigation. The motion measurements of the hub are provided by a Vectornav VN-200 IMU [1] that provides raw data for 3-D acceleration, orientation (heading, roll, pitch), and pressure measurements. The VN-200 was chosen over other alternatives due to its high accuracy of 0.1 degrees RMS for orientation and 0.05 m/s for velocity, and due to its relative low power consumption of 100 mA @ 3.3 V.

2. **Underwater Acoustic Ambient Noise.** Long-term measurements of acoustic noise are important for the modeling of the ambient noise in the sea. Connecting these measurements with external environmental phenomena, as well as with man-made activities, is very important in monitoring the health of the marine environment. Measuring the acoustic noise is also important for the development of robust underwater communication and detection techniques, that greatly rely on accurate models of the ambient noise. The measurement of ambient sound in water will be performed in the submerged hub using the AMAR G3 acoustic recording system [2]. The AMAR system is a self-contained acoustic measurement unit whose (two channel) raw data acoustic output is connected to the submerged hub for processing.

3. **Underwater Acoustic Detection.** The offshore location of THEMO makes it ideal for the monitoring of marine mammals and large pelagic fish. These species are at the top of the food chain, and their biomass serves as a good indication for the health of the marine environment. Through processing of passive and active acoustic signaling, the submerged hub will track the existence of species like Dolphins, sharks, tuna, and sea turtles. The passive measurements are conducted through the AMAR system, while active acoustic signals are generated by the Evologics SDM modems [3] and recorded at the AMAR system. Onboard processing is conducted by a combination of a Raspberry Pi 2 and a UdOO Board. Both passive and active acoustic measurements are scheduled according to a fixed period adjustable from the shore.

4. **Underwater Acoustic Communication.** The ability to connect from shore to the THEMO moorings allows the application of long-range underwater acoustic transmission both for the aim of testing underwater communication algorithms and for calibrating underwater acoustic propagation models. In this context, the two THEMO moorings serve as way points for the reception of such communication for simultaneous testing in different sea conditions. In this setting, the transmissions will be carried from a vessel. The recording of the signals will be based on the AMAR system.

2.2. Processing Units

For the processing units of the mooring and of the submerged hub, we considered the tradeoff between computational capability and power consumption. The former is important for a good processing capability since raw data transmission is not allowed based on the limited RF link capabilities. The power is of importance since both the processors on the buoy and on the submerged hub are extremely hard to reach for battery charging.

We considered the UDOO Neo Full [4], Raspberry Pi 3 [5], Pandaboard[6], BeagleBoard [7], BeagleBone Black [7] platforms, which are the main off-the-shelf processors with a strong development community. Among these options, the UDOO Neo Full board [4] had both the advantages of a powerful processor and a high capacity RAM. The UDOO also incorporates a fast

Ethernet interface. The power consumption is that of a typical ARM architecture board, and was measured to be 1.5 W in idle (but keeping an SSH connection up) and up to 2.3 W at full CPU usage.

Since available eMMC options are all of low capacity, we chose a 128 GB class 10 SD card storage. The operating system employed is Debian based Linux version, and the software developed employs the Linux standard library.

2.3. Energy Source

The energy supply for the submerged hub is a 37 V, 2300 Wh battery pack. A DC-DC converter of 12 VDC and 24 VDC supplies the power for the units. The capacity has been calculated based on the expected energy consumption of each component for a period of three months without charging. For this period, we anticipate 4368 hours in standby mode (energy consumption of 218 Wh), 20 hours in regular operation mode without use of sensors (energy consumption of 164 Wh), 80 hours in acoustic receiving mode (energy consumption of 896 Wh), 20 hours in acoustic transmitting mode (energy consumption of 840 Wh), 4 hours communicating with the secondary processor on the buoy (energy consumption of 52 Wh), and 4 hours collecting inertial measurements (energy consumption of 5 Wh).

While the above capacity has been calculated based on actual operation needs, unexpected need for at-sea charging is possible. To that end, we include a 600 W charger as part of the battery pack. Charging is based on the 90 m Ethernet cable connecting the hub to the buoy, and can be performed by a 220 VAC power from a boat.

To reduce current leakage, the battery is disconnected in standby mode. Power On/Off is performed through a relay mechanism operated by a TTL signal from the PC104. When the hub is On, the operation of the battery is monitored. This is performed via a designated electrical circuit contained within the battery pack to monitor the voltage current and to provide an estimate of the remaining capacity. This data is recorded at the hub processor, and is part of the status packets from the hub.

3. COMMUNICATION PROTOCOLS BETWEEN THE HUB AND THE BUOY

The aim of the submerged hub is to provide the means for real-time and long-term inspection of the marine environment. To that end, a fast and secure two-way data transfer between the processing units on the hub and the buoy is required. Considering the high energy limitations of the mooring, such communication must require low power. In this section, we describe the developed communications protocols.

The buoy-hub interface has been developed to be scalable and flexible to allow future connection of additional sensors onboard the submerged hub. The operation of the submerged hub is performed as a plugin from the THEMO main processor. The plugin includes scheduling and an execution of preset software files that can be altered remotely using the buoy communication system. Although it is possible to directly access the processor via ssh for debugging operations, we follow the plugin approach 1) since the radio connection to shore is not stable, and 2) to avoid direct access to the board for security reasons. The PC104 schedules the node session to start, by employing the crontab [9] Linux scheduling feature. Periodically, the PC104 transmits to shore the logs employing an ftp server.

Each plugin session is composed by the following scheduled sequence:

a. Power on secondary processor and the submerged hub at a defined time,
b. Synchronize the secondary processor with the PC104,
c. Transmission to shore of old logs that remained from last operation,
d. Removal of old logs from the secondary processor,
e. Uploading files to the secondary processor,
f. Script execution in the secondary processor,
g. Downloading results from hub to buoy,
h. Power off.

The protocol interfaces the main buoy's ftp server (onboard a PC104) with a secondary processor on the buoy that, in turn, directly connects to the processor on the hub. This way, only allowed operations are possible in the submerged processor whose maintenance is very complex.

The processes running in the secondary board are monitored with an svc daemon-tool [8] that restarts operations in the case of faults. An additional daemon process monitors the memory and the CPU usage, as well as the temperature of the secondary processor in the buoy. In particular, in case the temperature is above a certain threshold (87.5°C), the lowest priority process is terminated, while in case the board approaches dangerous conditions (above 91°C), the system status and logs are saved and the board is powered off.

To communicate among the shore station, the main processor, and the secondary board, we employ a web interface. When the radio link is active, the system uploads this information as well as other files to the PC104 using the html and ftp protocols. When the session starts, the PC104 operates the hub's plugin. This task is preceded by a power ON operation, performed by transmitting a TTL signal to the hub. Once this TTL is received, a relay opens the main battery of the hub and processing starts. All commands (e.g., synchronize a processor, run a script, switch off the board, etc.) are sent through a TCP socket.

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